Laser-driven Ion Acceleration with Cryogenic Hydrogen Targets*

S. Bedacht†1*, O. Deppert*[1]*, S. Geschwind*[1]*, R. Jaeger*[1]*, A. Kleinschmidt*[1]*, F. Mertins*[1]*, A. Ortner*[1]*, V. Schanz*[1]*, G. Schaumann*[1]*, A. Tebartz*[1]*, F. Wagner*[1]*, B. Zielbauer*[2,3]*, V. Bagnoud*[2,3]*, M. Roth*[1]*, and D.H.H. Hoffmann*[1]

[1]Technische Universität Darmstadt, Germany; [2]GSI, Darmstadt, Germany; [3]Helmholtz-Institut Jena, Germany

Abstract

We successfully demonstrated laser-driven ion acceleration with cryogenic hydrogen targets at *PHELIX*. By using short pulses with 200 J in 500 fs and the *uOPA* high contrast option [1] an intensity on target of around $5 \cdot 10^{20}$ W/cm^2 was obtained. This enabled the acceleration of ions from cryogenic hydrogen targets and plastic targets with energies up to 65 MeV/nucleon for protons, setting a new record for laser-driven ion acceleration at *PHELIX*.

Introduction

For laser-driven ion acceleration the mechanism of *Target Normal Sheath Acceleration* (*TNSA*) has been dominant for the last ten years. Typical experiments at *PHELIX* involving metal targets made from aluminum, copper, and gold with thicknesses in the range of 5 μm to 50 μm yielded proton energies of up to 40 MeV/nucleon. In order to achieve higher particle energies new mechanisms of laser-driven ion acceleration need to be exploited such as the *Laser Breakout Afterburner* (*BOA*) [2] scheme. This scheme relies on a phase of relativistic transparency of the target during the interaction with the laser, thus making high demands on both the driving laser pulse in terms of energy and temporal contrast as well on the target in terms of composition and thickness.

Setup

The experimental campaign *P060* was carried out in two runs of 10 and 20 shifts of *PHELIX* beam time in April and August of 2013, respectively. The experiment was set up inside the new target chamber in the *PHELIX* laser bay. It made use of the *uOPA* high contrast option [1] of the short pulse frontend and an off-axis parabolic mirror with an f/1.6 opening. With pulses delivering 200 J in 500 fs the peak intensity on target was on the order of $5 \cdot 10^{20}$ W/cm^2. For the production of hydrogen targets a custom made cryogenic target mount cooled by a cold head down to temperatures as low as 8 K was used. [3] The cryogenic hydrogen targets were produced just prior to the actual laser shot at the laser interaction point with a thickness of few μm to 100 μm. Additionally, thin plastic targets made from polymethylpentene with thicknesses in the range of 200 nm up to 1100 nm were used.

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† s.bedacht@gsi.de

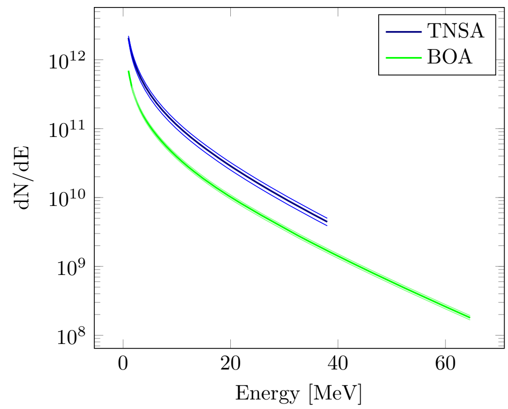

Figure 1: Particle distribution function dN/dE of laser-driven protons obtained from a 700 nm thick plastic target at *PHELIX* using radiochromic film. The blue and the green lines correspond to protons accelerated via the *TNSA* and *BOA* acceleration schemes, respectively.

Results

For the very first time pure cryogenic hydrogen targets and combinations of plastic substrates with layers of cryogenic hydrogen were employed for laser-driven ion acceleration. The pure cryogenic hydrogen targets yielded energies of up to 41 MeV/nucleon. Adding cryogenic hydrogen layers to 200 nm plastic substrates significantly improved the smoothness of the spatial profile of the accelerated ions and yielded higher ion energies of up to 57 MeV/nucleon. The shots at pure plastic targets yielded ion energies of up to 65 MeV/nucleon for a target thickness of 700 nm.

By tilting the target with respect to the laser propagation axis by an angle of about 10° two spatially separated ion beam profiles could be obtained. The ion beam along the target normal direction can be attributed to *TNSA* while the beam profile along the laser propagation axis corresponds to an acceleration via *BOA* [2]. The particle distribution function dN/dE of these two beams is shown in figure 1.

References

[1] F. Wagner et al., *Applied Physics B*, DOI 10.1007/s00340-013-5714-9 (2013)

[2] L. Yin et al., *Laser and Particle Beams*, DOI 10.1017/S0263034606060459 (2006)

[3] S. Bedacht et al., *GSI Scientific Report 2011*, PNI-PP-25, page 458 (2012)

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